STRUCTURAL AND FUNCTIONAL FAULT-TOLERANCE EVALUATION OF LOCAL AREA NETWORKS

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ABSTRACT

Fault tolerance attributes of Local Area Networks (LAN) have been evaluated in their structural (topologies) and functional (protocols) aspects. In relation to structural faults, a fault model has been developped and five topologies considered: SINGLE BUS, DOUBLE BUS, SINGLE RING, DOUBLE RING and BRAIDED RING. In relation to the functional fault tolerance of the protocols, in this paper the "token passing protocol" for buses of the type proposed in the IEEE 802 Normalization Project has been considered under the presence of faults caused by burst noise.

1. INTRODUCTION

Recent advances in communication technology have motivated a widespread success of distributed systems structured as Local Area Networks. An increasing concern in the Fault Tolerance attributes of such architectures has motivated research oriented to the evaluation of the capability of the LAN to sustain operation in presence of faults (AVI 78).

BUS and RING topologies have been contemplated in the IEEE 802 Project which proposes a normalization of Local Area Networks (IEEE 84). For this reason we have centered our attention to bus and ring structures. Also, functional aspects have been considered for the token bus protocol proposed by the IEEE 802 Project. A good tutorial by Liu on ring topologies evaluation can be found in (DALL 84). Recent results for rings can be found in (RAG 85). Fault tolerance of bus structures has been the object of intense research effort (PRAD 85).

2. EVALUATION OF FAULT TOLERANT STRUCTURES

Structures

The basic Local Area Networks topologies, BUS and RING have been considered with enhancements geared to increase their fault tolerance attributes. In Figures 1 and 2 the topologies evaluated are described.

Single and double bus structures have been considered. In the single bus case, the network fails if the bus fails or if a station forces incorrect states on the bus. In the double bus structure each station accesses the buses via independent interfaces realizing independent protocols at Physical, Medium Access Control and Logical Link Level, corresponding to levels 1 and 2 of the ISO-OSI Reference Model.

A well known token ring structure with some fault tolerance attributes has been proposed in the IEEE 802 Normalization Project. It consists of a single ring (Fig.2 (SR)) with bypass mechanisms to isolate faulty stations. The fault tolerancy of the ring requires the implementation of autotest procedures and depends highly on their efficency. Two fault tolerance enhancements discussed by Liu (DALL 84) have been considered.

In the double ring (Fig.2 (DR)) each station is connected via two independent unidirectional channels to its predecessor and two additional independent channels to its successor. In its normal operation, with no faults present, two rings rotating in oposite directions can be used. As indicated in Figure 2, bypass mechanisms to isolate faulty stations will be assumed present in the structure. One or more failures in the lines of the forward ring will be tolerated using the backward ring and vice-versa. A faulty station can be isolated either by activation of the bypass mechanisms or by folding the backward and forward rings in a unique ring. This last procedure can be used for situations when more than one station fails. Then, the adjacent non-faulty stations will be grouped in folded rings.

Finally a braided ring structure (Fig.2 (BR)) has been also evaluated. For this case there are also four communication lines interfaced to each node of the ring: two connecting to its immediate successors and two coming from the immediate predecessors. The "braid" lines are used to provide a redundant path in case of a fault in a "lob" (forward line + following station). The connectivity for the remaining non-faulty stations is preserved if no consecutive "lobs" fail and the "braid" lines needed to isolate the faulty "lobs" remain operational.

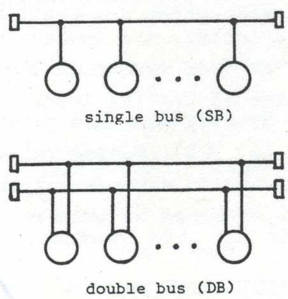


Fig. 1 Bus Topologies

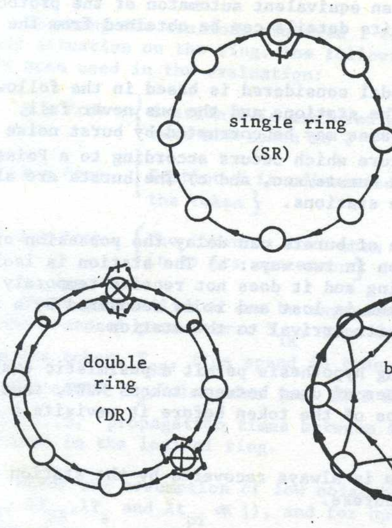


Fig. 2 Ring Topologies

Evaluation methodology

As a criterium to evaluate the goodness of a certain structure, a mesure of the communicability of the LAN has been considered. This measure has been used previously by Juanole (JUA 78) and Ihara and Mari (IHA 81). The "communicability" is defined as the mathematical expectation of the number of pairs of stations which may communicate, divided by the total number of pairs of stations of the network.

Formally:

$$C = \sum_{s \in S} C(s) \cdot P(s)$$

where:
$$C(s) = \frac{\sum_{i=1}^{K(s)} \binom{n_i(s)}{2}}{\binom{n}{2}}$$

and:
- S: Fault set of the LAN fault MODEL
- s: Fault state
- K(s): Number of grups of intercommunicable stations for fault state s. Each grup has cardinality $n_i(s)$ $i = 1, 2, \ldots K(s)$
- n: Total number of stations of the LAN

The Fault Model used is described by the following hypothesis: a) Any element of the structure (lines or station) is either in faulty or non faulty states, with probabilities termed availability (a) and unavailability (u= 1-a), and b) Failures on the elements are assumed independent of each other.

For single ring, double ring, single bus and double bus using bypass or disconnection mechanisms a mesure of the efficiency of this mechanisms is needed. We have introduced a confineability factor r, defined as the probability that the fault station remain isolated by the bypass mechanisms in rings or non affect the bus operation in buses. This events are also assumed independent of any other probabilistic event of the network.

To simplify the evaluation, it has been assummed the same availability for each element of a certain type: a_s for stations, a_l for "forward" and "backward" lines, $a_{l'}$ for "braid" lines and a_b for buses.

Based on the previous hypothesis, by combinatorial analisis, the following results are easily derived:

SINGLE BUS: $C_{SB} = a_s^2 \cdot a_b \cdot a_s'^{\,n-2}$

DOUBLE BUS: $C_{DB} = a_s^2 \cdot (2 a_b a_s'^{\,n-2} - a_b^2 \cdot (a_s + r^2(1-a_s))^{n-2})$

SINGLE RING: $C_{SR} = a_s^2 \, a_l^n \, a_s'^{\,n-2}$

DOUBLE RING: $$C_{DR} = a_s^2 \left(a_s'^{\,n-2} \left(2a_l^n + a_l^{2n} - 4a_l^{n+1} \frac{1}{n-1} \cdot \frac{1-a_l^{n-1}}{1-a_l}\right) + 2a_l^2 \frac{1}{n-1} \cdot \frac{1-(a_s' \cdot a_l^2)^{n-1}}{1-a_s' \cdot a_l^2}\right)$$

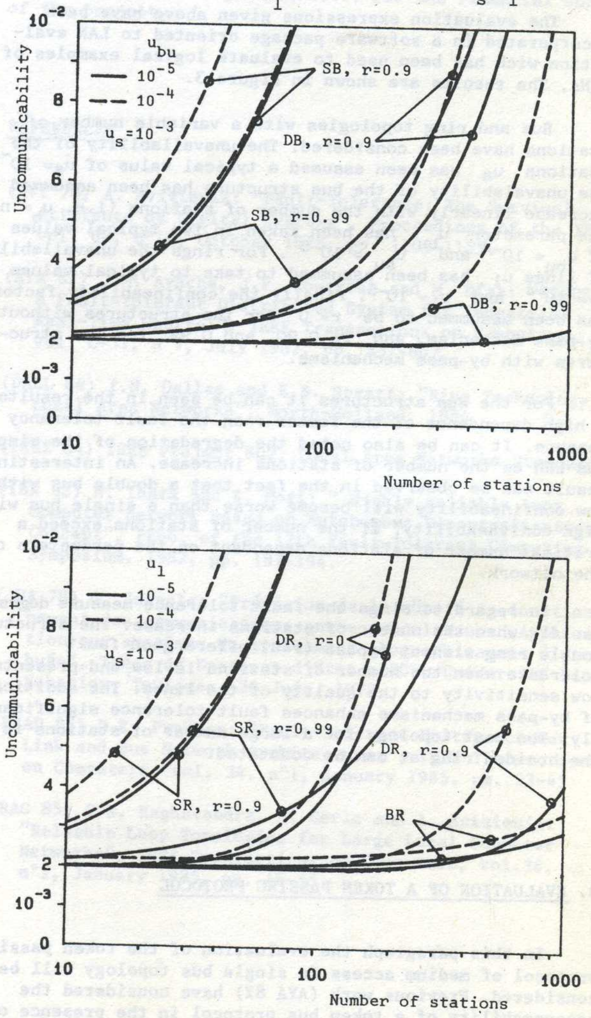


Fig. 3 Uncommunicability of bus and ring topologies as a function of the number of stations for several LAN parameter values.

$$\text{BRAIDED RING: } C_{BR} = \sum_{k=0}^{\lfloor n/2 \rfloor} \binom{n}{k} (1-a_s \cdot a_1)^k (a_s \cdot a_1)^{n-k} \, a_1'^{\,k} \, C_{BR}(k)$$

$$\text{with } C_{BR}(k) = 1 \quad \text{for } k=0$$

$$= \frac{n-2}{n} \quad \text{for } k=1$$

$$= \frac{\binom{n-k-1}{k-1} \cdot \binom{n-k}{2}}{\binom{n-1}{k-1} \cdot \binom{n}{2}} \quad \text{for } 2 \leq k \leq \left\lfloor \frac{n}{2} \right\rfloor$$

$$\text{with } a_s' = a_s + r(1-a_s)$$

Application examples

The evaluation expressions given above have been incorporated in a software package oriented to LAN evaluation wich has been used to evaluate logical examples of LANs. The results are shown in Figure 3.

Bus and ring topologies with a variable number of stations have been considered. The unavailability of the stations u_s has been assumed a typical value of $u_s = 10^{-3}$. The unavalability of the bus structure has been assummed to increase linearly with the number of stations (i.e. $u_b = n u_{bu}$) The parameter u_{bu} has been taken in two typical values of $u_{bu} = 10^{-4}$ and $u_{bu} = 10^{-5}$. For rings the unavailability of lines u_l has been assummed to take to typical values of $u_l = 10^{-4}$ and $u_l = 10^{-5}$. Finally the confineability factor has been assummed to be $r = 0$ for the structures without by-pass mechanism, and $r = 0{,}90$ and $0{,}99$ for the structures with by-pass mechanisms.

For the Bus structures it can be seen in the results, a high dependence of the factor r on the fault tolerancy measure. It can be also noted the degradation of the single bus LAN as the number of stations increase. An interesting result can be observed in the fact that a double bus with low confineability will become worse than a single bus with high confineability, if the number of stations exceed a critical number of stations dependent on the parameters of the network.

In regard to rings the fault tolerance measure degrades rapidly when the number of stations increase. The structure double ring without bypass (r=0) offers good fault tolerance when the number of stations is low, and presents low sensitivity to the quality of the lines. The addition of by-pass mechanisms enhances fault tolerance significantly. The best topology for a large number of stations is the braided ring as can be constated.

3. EVALUATION OF A TOKEN PASSING PROTOCOL

In this paragraph the evaluation of the token passing protocol of medium access in single bus topology will be considered. Previous work (AYA 82) have considered the recoverability of a token bus protocol in the presence of functional faults caused by the stations. In this paper we will center on the effect of noise burst on the token passing protocol proposed by the IEEE 802 Project.

In Figure 4 an equivalent automaton of the protocol is described and its details can be obtained from the referred document.

The Fault Model considered is based in the following assumptions: a) The stations and the bus never fail, b) The control frames may be corrupted by burst noise of transitory nature which occurs according to a Poisson process of rate λ bursts/sec, and c) The bursts are always identified by the stations.

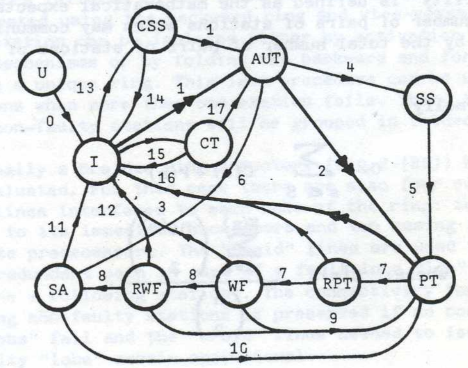
The presence of bursts can delay the possesion of the token by a station in two ways: a) The station is isolated of the logical ring and it does not receive temporaly the token, b) The token is lost and it is recovered by a station that delays its arrival to the station.

The following hypothesis permit a pesimistic evaluation of the number of uses between tokens NUBT, that is, the number of hops of the token before it revisits a station:

a) The token is always recovered by the station with lowest address.

b) The search of successor is achieved in states WF or RWF

c) Only the station considered (station 1) may be excluded from the logical ring.



TRANSITIONS

0 power up
1 token received
2 successor known & open window not required
3 token passed
4 successor known & open window required
5 window opened
6 successor not known
7 token pass failed
8 who follows not found
9 who follows found
10 successor found
11 successor not found
12 no pass token
13 insertion allowed
14 contention lost
15 BIT expired
16 competition lost
17 token gained

STATES

U UNPOWERED
I IDLE
AUT ACCEPT AND USE TOKEN
SS SOLICIT SUCCESSOR
PT PASS TOKEN
RPT REPEAT PASS TOKEN
WF WHO FOLLOWS
RWF REPEAT WHO FOLLOWS
SA SOLICIT ANY
CSS CONTENTION FOR SET SUCCESSOR
CT CLAIM TOKEN

Fig. 4 Equivalent automaton for the token-bus protocol.

Assuming the stations numbered 1 to n according to their situation on the ring, the following probabilities have been used in the evaluation:

p = Prob {Station 1 is exclused when n atempts to send the token to 2}

r = Prob {Station 1 is reinserted when n receives the token}

q_i = Prob {The token is lost when a station i sends it to its successor}

These probabilities can be expressed as functions of the protocol parameters: T_{TK}, time spend in transmitting the token, T_{SS}, time spend in transmitting frames set_successor, T_s, slot time (see IEEE 84), and t_{pi}, i= 1,...,n, propagation times between succesive stations in the logical ring.

Under the assumption of low noise burst rate (i.e. λT_{TK}, λT_{SS}, λT_s and $\lambda t_{pi} \ll 1$), and for burst duration negligeable, the expressions of the probabilities can be approximated by:

$$p = (\lambda T_{TK})^2$$

$$r = \lambda T_{SS}$$

$$q_i = 4 \lambda T_s (\lambda t_{pi} + \lambda^2 T_s T_{TK})$$

The distribution of NUBT can be evaluated using a Markov Chain with one absorbing state. The non absorbing states represent the visit of the token to a station with the two configuration assummed for the logical ring: Complete logical ring and ring with station 1 excluded.

The probability function to exceed a predetermined number of token hops is given under the pessimistic hypothesis indicated above for the station before the one with lowest address (worst case), for typical parameters. Three cases have been considered with burst rates 0,01 bursts/sec. , 1 burst/sec., 100 bursts/sec..

As can be seen in Figure 5 the probability to exceed the non-faulty operation (number of hops = number of stations of the token-bus) is negligeable for the low noise

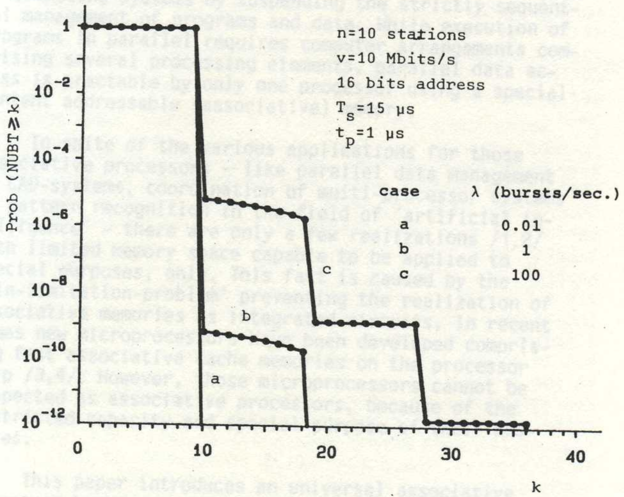


Fig. 5 Probability that the number of uses (token hops) between token possessions exceed k, evaluated for the worst case station.

case . On the other hand, when the noise increases there is a non negligeable probability to exceed a large number of hops, and in consequence, the time between token visits to a station may become large with a non negligeable probability.

4. CONCLUSIONS

The Fault tolerance attributes of Local Area Networks have been evaluated regarding the structure (topology) of the network in the basic Bus (single and double) and Ring (single, double and braided). The functional aspect of the protocol has been evaluated for a token bus topology with noise bursts on the lines. The methodologies proposed have been implemented in a software package and illustrative exemples have been discussed.

Acknowledgements

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REFERENCES

(AVI 78) A. Avizienis: "Fault-Tolerance: The Survival Attribute of Digital Systems", Proceedings of the IEEE, vol. 66, n°10, October 1978, pp. 1109-1125.

(AYA 82) J.M. Ayache, J.P. Courtiat and M. Díaz: "REBUS, A Fault-Tolerant Distributed System for Industrial Real-Time Control", IEEE Transactions on Computers, vol. C-31, n°7, July 1982, pp. 637-647.

(DALL 84) I.N. Dallas and E.B. Spratt: "Ring Technology Local Area Networks", North-Holland, 1984

(IEEE 84) IEEE Project 802. Local Area Networks Standard

(IHA 82) H. Ihara and K. Mori: " Highly reliable Loop Computer Network based on Autonomous Decentralization Concept", Proc. of the 12th Fault-Tolerant Computing Symposium, 1982, pp. 187-194.

(JUA 78) G. Juanole: "Prévision de la sûreté de fonctionnement des communications entre calculateurs. Application aux systèmes de traitement gèographicament distribués", Thèse de Doctorat d'Etat n°803, Université Paul Sabatier, Toulouse, 20 Juin, 1978.

(PRAD 85) D.K. Pradhan: "Fault-Tolerant Multiprocessor Link and Bus Network Architectures", IEEE Transactions on Computers, vol. 34, n°1, January 1985, pp. 33-45

(RAG 85) C.S. Raghavendra, M. Gerla and A. Avizienis: "Reliable Loop Topologies for Large Local Computer Networks", IEEE Transactions on Computers, vol.34, n°1, January 1985, pp. 46-55.